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TITLE: MODELING AND SIMULATION FOR PROCESS AND SAFEGUARDS
SYSTEM DESIGN

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14

MODELING AND SIMULATION FOR PROCESS AND SAFEGUARDS SYSTEM DESIGN*

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ABSTRACT

A computer modeling and simulation approach that meets the needs of both the process and safeguards system designers is described. The results have been useful to Westinghouse Hanford Company process designers in optimizing the process scenario and operating scheme of the Secure Automated Fabrication line. The combined process/measurements model will serve as the basis for design of the safeguards system. Integration of the process design and the safeguards system design should result in a smoothly operating process that is easier to safeguard.

I. INTRODUCTION

The safeguards system engineer must be knowledgeable of the process scenarios, operating schemes, and the process measurements and their associated errors when he designs a safeguards system. It is desirable that the process operate smoothly, with minimum downtime and recycle streams, to simplify the materials control and accounting system. The process designer would like assurance that the process scenario and operating scheme will provide the required product output. In addition, the process designer would like to be aware of potential bottlenecks and know that adequate buffer storage capacity has been provided. This paper describes a modeling and simulation approach that meets the needs of both the process and safeguards system designers.

Computer modeling and simulation was applied to the Secure Automated Fabrication (SAF) line¹ to be located in the Fuels and Materials Examination Facility, now under construction at the Hanford Engineering Development Laboratory, Richland, Washington. The SAF process line is scheduled to begin production of uranium-plutonium mixed-oxide fuel pins in 1987, with a design throughput of 6,000 kg/yr. During

evolution of the process design, many different process scenarios and operating schemes were modeled. In addition, a detailed study of the Boat Transport System in the SAF line was performed.

II. PROCESS DESCRIPTION

A. The SAF Process

In this paper, we shall be concerned only with the powder and pellet operations of the mixed-oxide fuel-fabrication process. A model of the operations of fuel pin fabrication is presently under construction. A schematic of the SAF line powder and pellet operations is shown in Fig. 1.

The SAF process commences with batching and blending of uranium oxide and plutonium oxide powders. An organic binder and pore former is added to the blended powders, followed by compaction and granulation. After the addition of lubricant to the granules, pellets are pressed at two independent pressing stations. The pellets are loaded into boats that pass through debinding and sintering furnaces. The sintered pellets are sampled and analyzed for conformance to specifications. The pellets are then ground to size and inspected. Finally, pellets are loaded into cladding and fabricated into fuel pins.

B. The Boat Transport System

The Boat Transport System is the vital link between several subsystems in the pellet operations part of the SAF line. The Boat Transport System consists of two loop conveyors and many interface conveyors that lead to or from other subsystems. A diagram of the system is shown in Fig. 2. Under normal operating conditions, boats will be loaded with green pellets in Pressing and Boat Loading and will be transferred onto a carrier on Conveyor Loop A. Boats are transported to the inlet of the Debinding Furnace, pass through the furnace, and move on

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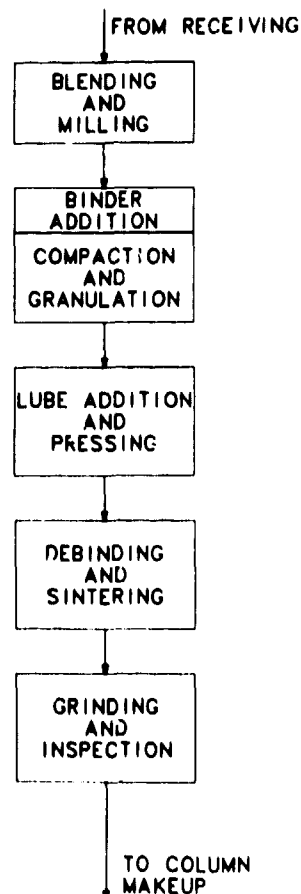


Fig. 1. A schematic of the SAF process.

the exit interface belt to Conveyor Loop B. Boats are then transported to the Sintering Furnace inlet. After passing through the furnace, boats exit to Conveyor Loop B and are transported to Boat Unloading. After unloading, boats are transferred to Conveyor Loop A, which transports them to Boat Inspection and Cleaning.

Sintered pellets requiring further degassing will be loaded into canisters and transferred from Pellet Storage onto Conveyor Loop A, which transports the cans to Property Adjustment. After processing in the furnace, the canisters are conveyed back to Pellet Storage on Loop A.

Green scrap is collected in special boats. These boats pass through the Debinding and Sintering Furnaces and remain on Loop B until they are removed once a week through the waste bagout port on Loop B and sent to Dry Recovery.

III. MODELING AND SIMULATION METHODOLOGY

A. Powder and Pellet Operations

Three different process scenarios and many operating schemes were modeled as the process design evolved. In all cases, two 100-kg batches of mixed oxide are processed each week. In the first scenario, a batch is taken as a unit through the entire process. Pellets are pressed twice a week; each pressing run lasts approximately two shifts. In the second scenario, the material is divided into 10-kg subbatches following the powder blending operations. Pellets are pressed five days/wk, one shift/day. In the third scenario, the operating scheme was changed to allow batching and blending on the same day and pellet pressing four days/wk, one shift/day.

The simulation was performed using the SLAM II simulation language² on a PRIME 750 computer. To yield information of use for process design, the process models must include much more detail than is ordinarily required for the design of a safeguards system. The necessary information was obtained by a detailed examination of the process flow sheets and operating schemes and by discussions with process design engineers. Equipment failure rates and mean repair times were estimated. Equipment failures were modeled to occur randomly. Simulation of one year's process operation required 45 min of computer time. In general 10 one-yr simulations were performed for each scenario or operating scheme to acquire sufficient statistics.

Process operation was also simulated with no equipment failures to determine the theoretical maximum output. Comparison of the results with those from simulations that include equipment failures but give satisfactory product yields allows the process designer to calculate the required uptime of each subsystem of the process.

B. Boat Transport System

The Debinding and Sintering Furnaces, Boat Unloading, Property Adjustment, and, of course, the Boat Transport System operate 24 h/day.

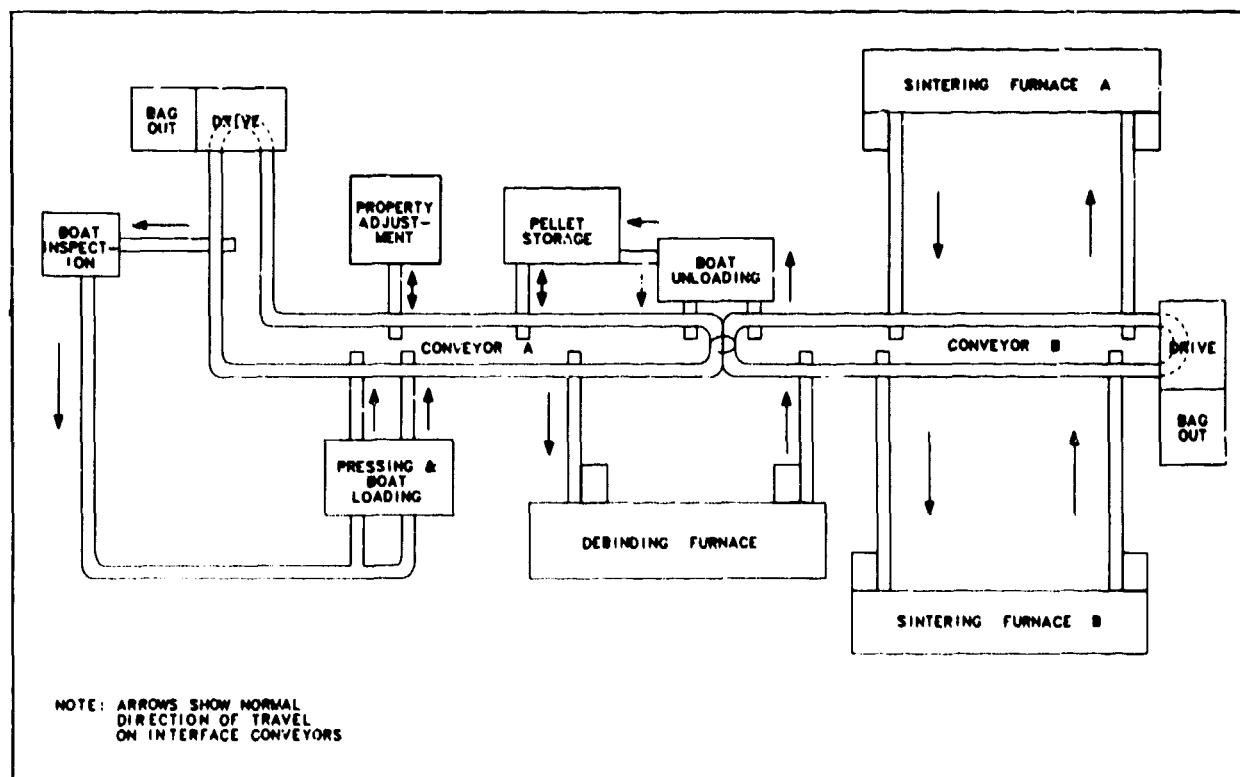


Fig. 2. Block diagram of Boat Transport System.

7 days/wk. The Boat inspection and Cleaning station, which is manually operated, was scheduled to operate only 5 days/wk, one shift/day. The simulation was performed to answer specific questions about the performance and operability of this system. Would these operating hours be sufficient to provide the necessary supply of clean boats to Pressing and Boat Loading? How many dirty boats would be waiting on Conveyor Loop A and the boat inspection inlet conveyor? How full are the conveyor loops and how much of the available time are they in operation, compared to design criteria? What operating scheme should be adopted for the Boat Cleaning and Inspection station?

Operation of the Boat Transport System was simulated, assuming no equipment failures, for 1000-2000 h. The results presented here are

for the third week of operation (hours 504-672) during which time the system is at steady state. Three operating schemes for boat inspection were considered.

1. Scheme A. All unloaded, dirty boats and all empty boats must be cleaned and inspected before re-use. An exception is that empty boats that come out of the Debinding Furnace may go directly to the Sintering Furnace if needed there; otherwise, they are transported to Boat Inspection by the shortest route. Boat Inspection and Cleaning is operated 5 days/wk, 12 h/day.

2. Scheme B. Boat Inspection and Cleaning is operated 7 days/wk, 9 h/day. All unloaded, dirty boats and all empty boats must be cleaned and inspected before re-use, as in Scheme A.

3. Scheme C. Empty boats that have passed through the Debinding and Sintering Furnaces may be re-used without first going through Boat Inspection. Twelve empty boats are maintained on Conveyor Loop B for use in the sintering furnace, as required. Boat Inspection and Cleaning is operated 5 days/wk, 8 h/day.

IV. RESULTS AND DISCUSSION

A. Powder and Pellet Operations

The simulation results include much valuable information to both the safeguards system engineer and the process designer. A partial list of available information is given in Table I. One important result is whether the design throughput has been achieved. Average yields for the process scenarios with and without equipment failures are given in Table II. Each value in the "with failures" columns is an average of the results obtained in 10 one-yr simulations.

The second process scenario obviously gave unsatisfactory yields. What bottleneck in the process caused the low throughput? Could yields above 6000 kg/yr be attained by changes in the operating scheme? An answer to the first question was sought by comparing the number of boats in the debinding and sintering furnace queues for Scenarios 1 and 2 and by examining plots of the time history of the loaded product boats waiting at the debinding furnace and actually in the furnace for Scenario 2. Comparison of the queue lengths (see Table III) showed that fewer boats were waiting to enter the furnaces in Scenario 2. The plots showed that, at regular intervals, there were no loaded boats in

TABLE I

PROCESS INFORMATION AVAILABLE FROM MODELING AND SIMULATION

- Total throughput under normal operation and under upset conditions
- Scrap accumulation
- Surge storage capacity needed
- Identification of pinch points
- Minimum and average processing times
- Effect of variations in processing rates
- Number of failures and total downtimes of key equipment items
- Queue lengths at process operations
- Equipment utilization factors
- Effect of alternative process line scenario or operating schemes

TABLE II
AVERAGE PRODUCT YIELDS

Process Scenario	With Failures		Without Failures	
	Yield (kg)*	No. of Batches	Yield (kg)	No. of Batches
1	7457	88.6	8366	99
2	5317	66	7160	88
3	6407	80	7751	96

*Values are the averages obtained in 10 one-yr simulations.

the queue and no loaded boats in the debinding furnace. The bottleneck was found to be at Binder Addition, where binder was added to 4-kg sub-batches of mixed oxide in cans, the cans sealed, and the contents blended--one can at a time. This time-consuming operation affected all subsequent process steps.

Several additional simulations were performed to determine if higher throughput could be attained by a change in operating scheme. The major modification involved processing 5 batches every 2 wk, instead of 2 batches/wk. Other modifications involved keeping spare can handling equipment on hand to use as replacements for malfunctioning units and using the spare sintering furnace or another furnace to process green scrap. The results of these simulations, summarized in Table IV, show that the process scenario and equipment were not limiting factors and that satisfactory yields may be achieved by appropriate changes in the operating scheme.

TABLE III

COMPARISON OF QUEUE LENGTHS FOR PROCESS SCENARIOS 1 AND 2

	Debinding Furnace	Sintering Furnace
Maximum length		
Scenario 1	181	197
Scenario 2	109	128
Average length		
Scenario 1	25	67
Scenario 2	10	23

TABLE IV

EFFECT OF CHANGES IN OPERATING SCHEME:
SCENARIO 2

Operating Scheme	Product Yield (kg/yr)*
Two batches/wk	5317
Five batches every 2 wk	
Nominal	6135
Spare can-handling equipment	6524
Green scrap through other furnace	6620

*Average of results from 10 one-yr simulations.

The simulation results permit construction of process materials balances that include the total quantity of scrap and analytical samples accumulated during the year. A typical materials balance for one year's operation is given in Table V. This information is useful in the design of an adequately sized dry scrap recovery process.

The simulation results also include data on the average and maximum number of boats in use, the number of boats on the loop conveyors, queue lengths and waiting times at various process operations, the maximum number of cans of pellets in surge storage areas, and the number of failures and total downtimes of key equipment items. Equipment failures were modeled to occur at random times. When the Weibull distribution with the shape parameter set equal to 3.5 was used, the mean of the range of failures and repair times obtained in the simulation agrees well with the estimated values. The results of the simulations allowed determination of potential bottlenecks in the process and estimates of capacities of in-process storage areas that would be required under upset conditions.

The simulation enables the safeguards system designer to track a production batch through the process as a function of time and location. In actual process operation, all nuclear material will be measured and identified as it passes from one processing area to another, and materials balances will be calculated within 24 h. In the future, comparison of the process data with information given by computer simulation will aid the process operator in detecting any abnormalities in a timely manner.

TABLE V

TYPICAL MATERIALS BALANCE

Stream	Quantity (kg/yr)	
Input	9064.83	
Output		
Product	7582.25	83.64%
Scrap	1159.02	12.79%
Samples	218.28	2.41%
Sintering weight loss	41.96	0.46%
In-process inventory	63.32	0.70%
Total Output	9064.83	100.00%

B. Boat Transport System

Simulation of the three operating schemes gave data on the total number of boats in use, the number of boats on each conveyor loop, the usage of each loop (hours/week), the length of the queue of dirty boats at Boat Inspection, and the available clean boats at the inlet to Pellet Pressing and Boat Loading. Hourly values were calculated for four of these parameters.

Of the three operating schemes investigated, two gave satisfactory results. Scheme B, in which the Boat Inspection and Cleaning station is operated 7 days/wk, 9 h/day, is satisfactory if all boats must be cleaned and inspected before re-use. Scheme C, in which Boat Inspection is operated 5 days/wk, 8 h/day, is suitable if empty boats may be re-used without cleaning and inspection. In both of the satisfactory schemes, the conveyor loops are never more than 45% filled and are in operation less than 30% of the available time, which meets design specifications.

Some results of the simulation for Scheme A are given as an example of the output available and to demonstrate why Scheme A was unsatisfactory. The results are summarized in Table VI and Figs. 3-5. The maximum number of boats on Loop A is 89, and the average number exceeds 65 (which is 50% of the capacity, the design specification) on Monday, Tuesday, and most of Wednesday (see Fig. 3). Loop B is always less than one-fourth full. The number of boats processed daily at Boat Inspection is 53 Monday through Thursday and 42 on Friday. This processing rate is insufficient to furnish the number of clean boats required at Pressing and Boat Loading

TABLE VI

SIMULATION SUMMARY FOR SCHEME A

All boats pass through Boat Inspection.

Boat Inspection and Cleaning operated 5 days/wk,
12 h/day.

Total boats in use: 145 regular + 14 scrap
boats.

Maximum number of boats on Loop A: 89

Maximum number of boats on Loop B: 25

Loop A in use 26.85% of time (45.11 h/wk)

Loop B in use 22.15% of time (37.21 h/wk)

Maximum length of queue

Debinding Furnace 32 boats

Sintering Furnace 32 boats

Boat Inspection 98 boats

Maximum number of clean empty boats available
(before weekend) 78

during the first part of the week (see Fig. 4). Additional clean boats would have to be bagged in, a time-consuming operation. Further, the queue of dirty boats at the inlet to Boat Inspection is very long most of the week, diminishes briefly on Friday and Saturday and then quickly builds up again to a maximum of 98 (see Fig. 5). Most of these boats must be stored on Conveyor Loop A. Clearly, Scheme A is unacceptable.

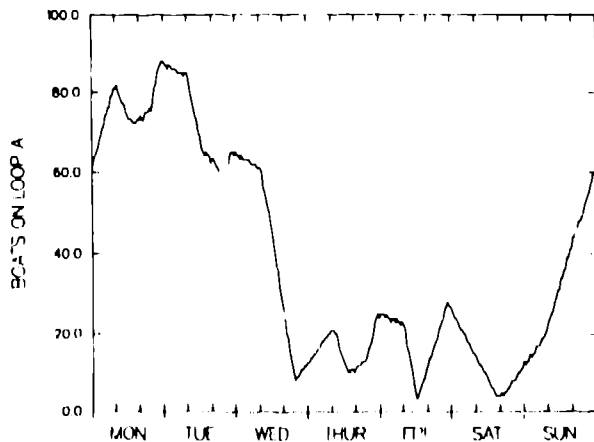


Fig. 3. Boats on Conveyor Loop A, Scheme A.

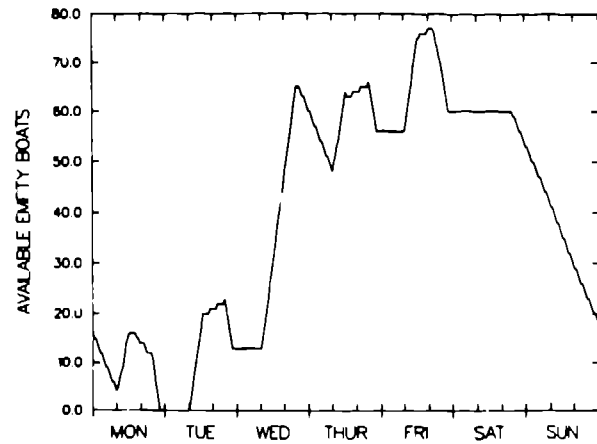


Fig. 4. Available clean boats, Scheme A.

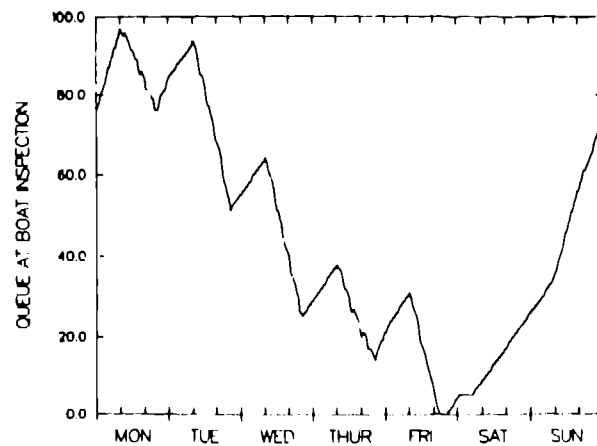


Fig. 5. Inlet queue at Boat Inspection, Scheme A.

V. SAFEGUARDS SYSTEM DESIGN

The process design for the SAF line is not yet final. Additional modeling and simulation of the process and the boat transport system is in progress. Data on process measurements are being added to the powder and pellet operations model. The combined process/measurements model will serve as the basis for design of the safeguards system. Various materials control and accounting schemes can then be tested to determine their sensitivity for detection of loss of

material. Because more than 2000 kg of plutonium oxide will be fabricated into mixed uranium-plutonium oxide fuel pellets annually, selection of an effective safeguards system is of prime importance.

VI. CONCLUSIONS

The computer modeling and simulation approach has been valuable in estimating in advance how well a given process scenario or operating scheme would perform. The results have been useful to the process designers at Westinghouse Hanford Company in optimizing their designs for the configuration and operation of the SAF line.

In the past, safeguards systems had to be designed to fit an existing process. Now, for the first time, the safeguards system engineer

has participated in the process design. The result should be a smoothly operating process that is easier to safeguard.

ACKNOWLEDGMENT

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REFERENCES

1. D. H. Nyman, E. M. Benson, J. M. Yatabe, T. T. Nagamoto, "Remote Fabrication of Nuclear Fuel: A Core Automated Fabrication Overview," *Trans. Am. Nucl. Soc.* 39, 982 (1981).
2. A. A. B. Pritzker and C. D. Pegden, Introduction to Simulation and SLAM (John Wiley and Sons, Inc., New York, 1979).